US HL-LHC Accelerator Upgrade Project

MQXFA04 Coils Acceptance Review

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1. Goal & scope

The HL-LHC AUP project is planning to start assembly of MQXFA04 magnet in November 2019. MQXFA04 is the second pre-series low-beta quadrupole (MQXFA) to be used in Q1 and Q3 for the High Luminosity LHC. If MQXFA04 meets MQXFA requirements [1] it will be used in the first Q1/Q3 cryo-assembly to be installed in the HL-LHC.

AUP is planning to use QXFA coils 203, 206, 112 and 115 for MQXFA04 assembly, and a 5th coil as spare coil. The reviewers are requested to assess that the 5 proposed coils and their conductor meet specifications [2], and to evaluate the impact of non-conformities in strands, cables and coils.

2. Charges

The committee is requested to answer the following questions:

1. Do the proposed coils meet MQXFA coil specifications [2]?

YES, see Findings/Comments below.

2. Are conductor/coil fabrication and QC data of the proposed coils adequate for a thorough evaluation and for allowing MQXFA04 to meet MQXFA requirements [1]?

YES, however there is some room for tightening up process procedures. See Findings/Comments below.

3. Are there major non-conformities? If answer is yes, have they been adequately documented and processed?

The are no major non-conformities.

4. Do you have any other comment or recommendation regarding conductor or coils for allowing MQXFA04 to meet MQXFA requirements [1]?

There are still a few issues that need to be better understood. See Findings/Comments below.

Findings/Comments

Conductor

The in-coming strands from OST are all within specification with occasional sections of some strands that are above the strand diameter specification. (Cable 1094). However, all the cable dimensions are well within specification and very uniform in cable width and thickness along the length of the cable. The electrical performance of the cables was checked with a minimal number of tests of samples reacted with the coil; one round wire and two extracted strands. The Committee understands this to be the accepted protocol. RRR was checked after cable fabrication using extracted strands. These RRR

measurements were done for the major and minor edges and the straight section between the edges. All measurements show that the cables meet acceptance criteria.

Coil	Cable	OST RRR – Round-strand Average	OST RRR-Rolled-strand Avg	% Copper in strand x-section
203	1096	315	236	53.8
206	1103	242	147	54.7
112	1100	318	214	54.1
113	1094	322	225	53.8
115	1102	263	154	55.1

From the perspective of RRR and % of copper, cables in coils 203,112 and 113 are similar, whereas cable for coils 206 and 115 are similar. All cables have sufficient critical current and temperature margin.

FNAL Coils 112, 113 and 115

The Committee notes that thermal monitoring of the heat-treatment of the coils is an issue at FNAL and also at BNL. This may be an issue of calibration of the individual thermal couples. There are instances where the spread or range in the thermal couple temperatures at 665 ^{0}C show a range almost twice the target based on the oven specification of 6 ^{0}C (±3 ^{0}C). For example, in coil 112 the spread of the last plateau is larger than the spec.

The Committee suggests that AUP coordinate with CERN that is carrying out a thorough analysis of the reaction cycles and is defining acceptance criteria based on the temperature measurements during reaction.

Several DR's were recorded for the coils; all were resolved. It is noted that the coil lengths for 113 and 115 are *close to the bottom range of* the design goal of 4532 ± 5.0 mm as noted in the FDR. There was no mention of pole gaps along the length. The Committee suggest considering modifying the FDR Coil length according to measured values.

From the FDR :

To meet the requirement of a magnetic length of 4.2 m, the overall coil length will be 4.532 m.

Table 5.1 Coil Dimensional Specification Dimension (mm) Tolerance (mm)

Inner radius	74.750	± 0.25
Outer radius	113.376	± 0.25
Coil to midplane gap	0.125	± 0.05
Coil length	4532	± 5.0

	Cable ID	Total (m)	L1 (m)	L2 (m)	Coil Length (mm)
QXFA 112	1100	427.1	188.2	238.9	4533
QXFA 113	1094	427.5	188.5	239.0	4529
QXFA 115	1102	428.8	188.5	240.3	4528

BNL Coils 203 and 206

Thermal couple monitoring for the heat treatment is also an issue at BNL with one of the reactions showing a range of thermal couple readings of 12 ^{0}C at 665 ^{0}C. Also noted that the high temperature plateau for 206 was 660 ^{0}C. That is outside the 665 ± 3 ^{0}C requirement used by CERN, and at the bottom range of the 665 ± 5 ^{0}C spec used by AUP. In coil 203 an issue related to thermocouples occurred in the last plateau showed a larger spread.

Coil lengths similar to FNAL coils are at the low end of the design target. This may not be a concern if all coils behave similarly during reaction.

Coil electrical tests

Electrical checks meet all acceptance criteria; though after transport there remain some questions regarding Hi-Pot test results at LBNL (Coil 113). In this coil, pole segment 3 shows a weakness in coil to pole on the order of 20M-ohm that was not observed prior to shipment. It is noted that the Coil-to-Pole voltage has been reduced to 100 V from 500 V.

It is possible that shipment conditions play a role (for example, humidity…) in the electrical test after shipment. The Committee feels that it would be prudent to investigate the possible causes of degradation of the coil-pole electrical resistance with the intent to modify shipping and storage conditions.

Coil size measurements (azimuthal)

In coils 112, 113, 115 a large shift of the pole key slot is measured in the last pole piece close to the LE. This will be accounted for during coil pack assembly by removing or machining the pole key toward the LE. At this time, no clear reason for this shift has been found.

At the time of the review the analysis on the shifting of coil 206 during shipping was not completed. In the meantime, the FE analysis was completed with the following results.

- 1g upward only on the coil;
- 10g upward applied on all the parts.
- 10g side-way applied on all the parts.

In all cases the coil strain is below the specification of < 500 microstrain with a large margin. The DR was closed with the disposition to use the coil as is. Lessons learned from the coil 206 shipping experience should mitigate risk on future shipments.

Recommendations

1. Perform coil-to-ground voltage calculations in a scenario where two coils have a RRR of 150 and two with RRR of 300 all have the same copper fraction in the strand.

2. Open a discrepancy report for all the reaction cycles that do not meet the specifications.

3. Continue the investigation to identify the possible causes of the shift of the pole key slot.

3. Technical information

Committee
Steve Gourlay – LBNL, chairperson
Arup Ghosh – BNL, retired
Paolo Ferracin – CERN

Date and Time
October 30, 2019. Start time is 7/9/10/15 (LBNL/FNAL/BNL/CERN)

Location/Connection
Video-link by Zoom, info by email.

Link to agenda with talks and other documents
https://indico.fnal.gov/event/22074

4. References

1) *Acceptance Criteria Part A: MQXFA Magnet*, US-HiLumi-doc-1103.
2) *MQXFA Final Design Report*, US-HiLumi-doc-948 sections 3 and 5.1.1; and *QXFA Coil Fabrication Electrical QA*, US-HiLumi-doc-521 step 16.